S71E-11 1135h

Observations that Constrain the Scaling of Apparent Stress

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Slip models developed for major earthquakes are composed of distributions of fault slip, rupture time, and slip velocity time function over the rupture surface, as divided into many smaller subfaults. Using a recently-developed technique, the seismic energy radiated from each subfault can be estimated from the time history of slip there and the average rupture velocity. Total seismic energies, calculated by summing contributions from all of the subfaults, agree reasonably well with independent estimates based on seismic energy flux in the far-field at regional or teleseismic distances. Two recent examples are the 1999 Izmit, Turkey and the 1999 Hector Mine, California earthquakes for which the NEIS teleseismic measurements of radiated energy agree fairly closely with seismic energy estimates from several different slip models, developed by others, for each of these events. Similar remarks apply to the 1989 Loma Prieta, 1992 Landers, and 1995 Kobe earthquakes. Apparent stresses calculated from these energy and moment results do not indicate any moment or magnitude dependence. The distributions of both fault slip and seismic energy radiation over the rupture surfaces of earthquakes are highly inhomogeneous. These results from slip models, combined with underground and seismic observations of slip for much smaller mining-induced earthquakes, can provide stronger constraint on the possible scaling of apparent stress with moment magnitude **M** or seismic moment. Slip models for major earthquakes in the range **M**6.2 to **M**7.4 show maximum slips ranging from 1.6 to 8 m. Mining-induced earthquakes at depths near 2000 m in South Africa are associated with peak slips of 0.2 to 0.37 m for events of **M**4.4 to **M**4.6. These maximum slips, whether derived from a slip model or directly observed underground in a deep gold mine, scale quite definitively as the cube root of the seismic moment. In contrast, peak slip rates (maximum subfault slip/rise time) appear to be scale invariant. A 1.25 m/s slip rate for one of the mining-induced earthquakes was estimated by dividing the corresponding slip observed at depth by the duration of the seismically-recorded slip pulse. Peak slip rates determined from the slip models for the major earthquakes are similar, ranging from about 0.8 to 4.8 m/s. Thus, for earthquakes in the moment magnitude range 4.4 to 7.4, the peak slip rate shows no dependence on **M**. Whatever variation there is in slip rate is probably due to factors related to the strength of the seismogenic rock mass such as depth. These observations support the idea that apparent stress does not vary systematically with seismic moment inasmuch as the apparent stress is determined by slip rate. Indeed, our finding that fault behavior of **M**4.4 earthquakes can be scaled readily to events of **M** greater than 7 with slips up to about 8 m suggests, quite persuasively, that the source physics for crustal earthquakes is much the same over this magnitude range. Interestingly, the mining-induced earthquakes involved brittle failure across very old pre-existing faults for which the cohesive strength is high and the pore pressure is zero, due to mining operations.

S71E-12 1150h

Energy Released by an Asperity Model of an Earthquake

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Estimating the energy released by an earthquake is a difficult problem because reliable data for the entire frequency spectrum of the source are generally not available. This difficulty is often circumvented by making various assumptions about the source and its spectrum, the most common being that stress, slip, and hence energy release are rather uniformly distributed over the fault surface. However, recent empirical and theoretical studies of small and moderate sized repeating earthquakes have raised questions about this general assumption of a homogeneous earthquake source. Observations that the repeat times for small repeating earthquakes along the San Andreas fault near Parkfield and Stone Canyon scale with the scalar moment to the 1/6 power can be explained by an asperity model of an earthquake based upon the analytical solution to the exterior crack problem. A characteristic of this asperity model is a very heterogeneous stress field, one that can not be described by a single parameter such as stress drop. This asperity model has been extended to include an estimate of energy release and it has been found that energy scales with the scalar moment to the - 1/3 power. This appears to argue for nonconstant scaling of apparent stress with moment, although the scaling of energy release could be offset by an opposite scaling of seismic efficiency, a parameter not constrained by our approach. Another interesting possibility suggested by the asperity model is that the moment and energy observed in the far field may have derived their major contributions from rather different parts of the fault.

S72A MCC: Hall C Sunday 1330h

Shallow, Near-Surface Imaging Posters

Presiding: **F Scherbaum,** University of Potsdam**; R Gritto,** Lawrence Berkeley National Laboratory

S72A-1124 1330h POSTER

Detecting low Velocity Anomalies Combining Seismic Reflection With First Arrival Seismic Tomography

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In the present study seismic reflection techniques and high resolution seismic tomography are combined to determine location and geometry of shallow low velocity anomalies. Underground cavities (mines), water flows (formation with loose sand), etc. are geologic features characterized by slow seismic velocities and are targets of considerable social interest. Theoretical considerations (Snell's law) suggest that low velocity anomalies are undersampled and therefore badly resolved by ray tracing methods. A series of synthetics simulations have been carried out to asses the resolving power of the different methodologies. A 400m$\times$50m two dimensional velocity model consisting of a background velocity gradient in depth from 3000 to 4000 m/s which included a rectangular low velocity anomaly (300 m/s). This anomaly was placed between 10m and 30m in depth and between 180m and 220m in length. The synthetic data calculation and the tomographic inversion have been done with absolutely independent programs. The data has been created using a 2D finite differences wave propagation acoustic algorithm. The tomographic inversion has been performed using two different software packages. The first one uses a combination of ray tracing a finite differences schemes to estimate the forward problem and an iterative conjugate gradient matrix solver to calculate the inverse. The second software package uses a modified Vidale scheme (Eikonal equation) to solve the forward problem and a LSQR to solve the inverse problem. The synthetic data were used for the inversions and for the generation of a conventional stacked section simulating a high resolution seismic reflection transect along the velocity model. The conventional stack images the diffractions caused by the velocity anomaly, which provided the location and extent of the low velocity anomaly. The inversions schemes provided estimates of the velocities, however, the tomograms and the ray tracing diagrams indicated a low resolution for the anomaly.

S72A-1125 1330h POSTER

Imaging Brittle Fracture Zones:Tomo-Datuming in a Granitic Pluton

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Wave equation datuming was used as a substitute to conventional refraction static corrections. This resulted in improved 2-dimensional high resolution seismic reflection images. A high resolution seismic reflection data set forms a multi-seismic data acquisition experiment in southwestern Iberian Peninsula that was used to test this processing scheme. The data was acquired with the aim of characterizing and mapping the fracturation of a granitic body (Albala pluton). An accurate near surface velocity model was derived from high-resolution seismic tomography using the traveltimes and the locations of sources and receivers as initial parameters. The tomographic algorithm uses a forward travel time calculation based on a finite difference algorithm and solves the linearized inverse problem by iterative conjugate gradient matrix solvers. The advantage of using wave equation datuming over refraction statics it properly propagates the recorded wavefield to the new datum, instead of applying vertical time shift to the data traces. This fact improves the signal-to-noise (S/N) ratio of the shot gathers and restores reflections and diffractions, providing better seismic images. The study area is characterized by strongly variable near-surface velocities and rugged surface topography. The stacked sections show a prominent dipping reflector that correlates with the main structure of the study area, North Fault. The diffractions correlate with sub-vertical structures (i.e.dikes) identified at surface.

S72A-1126 1330h POSTER

A Trial of the Delineation of Gas Hydrate Bearing Zones using Seismic Methods Offshore Tokai Japan

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MITI Research Well 'Nankai Trough' was drilled at offshore Tokai Japan in 1999/2000 and the existence of gas hydrate was confirmed by various proofs through borehole measurement or coring. It gave so big impact to the view of Japanfs future energy resources and other scientific interests.The METI, Ministry of Economy, Trade and Industry, has started the national project "Methane Hydrate Exploration study" in Japan since the fall 2001.

Bottom Simulating Reflectors (BSRs) were widely found on the marine seismic data acquired offshore Japan especially in the shelf-slope near Nankai Trough. BSRs are thought to be the bottom of gas hydrate stability zones, we cannot, however, get the information of gas hydrate bearing zones, such as the height of those, the porosity, the gas hydrate saturation etc, only from BSRs. In order to estimate the amount of gas hydrate accurately, we have to get those reservoir parameters of gas hydrate bearing zones from marine seismic data. The velocity of these zones is greater than that of the surrounding sediment, because pure gas hydrate has high velocity that is more than 3,000 m/s. This means the interval velocity is the key for exploration of gas hydrate.

First, we have tried to image the gas hydrate bearing zones from seismic stacking velocity analysis. After the conversion to interval velocity from NMO velocity by Dix's equation, we imaged the P-wave velocity section through 2D seismic line. We successfully imaged high velocity zones above BSRs and low velocity zones beneath BSRs on P-wave velocity section. But the resolution of the section from the velocity analysis is not so high. Although we have only two adjacent well log data on the seismic line, in order to make more detailed map, we tried to execute the seismic impedance inversion with MITI Nankai Trough Well data. We made a simple initial model and inverted to seismic impedance value. We got the good impedance section and delineated the gas hydrate bearing zones through it. JNOC, Japan National Oil Corporation, and METI conducted three 3D seismic surveys at offshore Tokai Japan in 2002 and they will drilled some research well at the same area from 2003 to 2004. We hope to image 3D gas hydrate bearing layers from the 3D seismic data and well results. To image the gas hydrate bearing zones, we will try to detect interval velocities from seismic data and to resolve much higher, we are planning to execute the multi-seismic attribute analysis and AVO inversion.

S72A-1127 1330h POSTER

Shallow Crustal Structure of Chicxulub Impact Crater Imaged With Seismic, Gravity and Magnetotelluric Data: Structure of the Central Uplift and Origin of the Cenotes Ring.

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The shallow crustal structure of the onshore portion of the Chicxulub impact structure (Yucatan, Mexico) has been studied with seismic, gravity and MT exploration. A dispersion analysis of Rayleigh waves along a 150-km long, east-west profile allowed to image the shallow Tertiary cover to a depth of 400 m. The thickness of the first layer increases towards the central basin, from less than 100 m immediately outside, to more than 200 m in the terrace zone. The second layer also increases its thickness from about 150 m outside the crater rim, to around 250 m in the vicinity of the rim. At the center of the crater the first layer is again about 100 m thick. The increase in thickness of the first two layers as we approach the sinkhole ring from the exterior of the crater is consistent with the existence of a central basin. The velocity distribution along our profile does not have low-velocity layers. Thus, a low velocity layer observed in the Tertiary cover in a previous study, may be delimited to a ring around the crater center. The inferred inward slope of the two shallow layers immediately outside the central basin correlates with a smooth gravity gradient. A gravity model based in detailed measurements along our profile enable us to associate the fracturing that favored the development of the sink holes at the eastern rim with the ring fracture mapped by offshore seismic line. Finally, preliminary results of ongoing magnetotelluric (MT) studies support the existence of the central structural high.

S72A-1128 1330h POSTER

Tube-Wave Suppression in Single Well Seismic Acquisition

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Single well seismic acquisition uses sources and sensors in the same borehole to image subsurface properties near the borehole. Single well data can image larger rock volumes than standard well logging by using lower frequencies (longer wavelengths) and longer source-receiver spacing. However, single well seismic imaging, like other borehole seismic methods, is significantly hampered by the presence of borehole tube-waves.

A tube-wave suppressor has been tested using single-well seismic equipment at the Lost Hills (California) oil field. The suppressor uses a gas filled bladder kept slightly above borehole fluid pressure. The field tests show a measurable reduction in tube-wave energy as compared to body waves propagating in the surrounding reservoir rock. These tests used two different seismic sources. When using a high-frequency (500 - 4000 Hz) piezoelectric source, the P-wave to tube-wave amplitude ratio is increased by 33 dB. When using a lower frequency (50 - 350 Hz) orbital vibrator source, the S-wave to tube-wave amplitude ratio was increased by 21 dB while the P-wave to tube-wave amplitude ratio was increased by 23 dB. These reductions in tube-wave amplitudes significantly improve single-well data quality.

It is notable that the orbital vibrator source generates shear-waves which are vertically propagating and horizontally polarized, and therefor potentially useful for shear-wave anisotropy studies. At Lost Hills, the reservoir has shear-wave velocity less than the tube-wave velocity, so only the effectiveness of the tube-wave suppressor allowed measurement of shear-waves. Both P- and S-wave single well results will be presented.

S72A-1129 1330h POSTER

Near-surface Faults and Structure of the Western Santa Clara Valley, California as Seen From High-Resolution Seismic Reflection and Refraction Images

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The U.S.G.S acquired an 10-km-long, high-resolution seismic reflection/refraction profile across the western Santa Clara Valley in the fall of 2000. The seismic profile, which originated within Franciscian rocks of the Santa Cruz Mountains and extended across the Cupertino basin to downtown San Jose, was designed to image shallow (upper 500 m) subsurface structure and stratigraphy along its length. The seismic profile crossed the Monte Vista fault zone and other buried faults inferred to exist beneath the western Santa Clara Valley. High resolution images were provided by seismic sources and geophones that were spaced at 5-m increments along the entire profile, resulting in CDP intervals of 2.5 m. The data were recorded on a 240-channel moving array, which yielded maximum folds over 200 along many segments of the profile. Both velocity and reflection images were developed from the data. Near-surface velocities range from about 500 m/s in the shallow subsurface of the Cupertino basin to more than 3000 m/s in surficial Franciscian rocks of the Santa Cruz Mountains. Reflectivity along the profile varies with rock types, with more reflective strata associated with sediments of the Cupertino basin than Franciscian rocks rocks of the Santa Cruz Mountains. Small offset faults and folds are apparent at several locations along the profile. Larger-offset, south-dipping faults are apparent within the Monte Vista fault zone and at least one other fault zone near the central Santa Clara Valley. The high-resolution images show that the faults extend to the near-surface, suggesting that recency of faulting may be accessed with paleseismological methods. If active, these faults may pose significant hazards to the Santa Clara Valley because they are located in highly populated areas. Furthermore, thick, low-velocity sediments observed in high-population areas along the parts of the profile may amplify seismic waves generated by movement on either local or regional faults, posing another potential hazard to the valley.

S72A-1130 1330h POSTER

Waveform Tomography Applied to the High Resolution HAFB Dataset

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We have applied waveform tomography to a vertical seismic profile (VSP) and surface seismic dataset from Hill Air Force Base (HAFB), Utah, acquired in 2000 along with 3D surface reflection and 3D surface tomography experiments. Previously (Gao et al. , 2001) we had applied waveform tomography to the same dataset using first arrival waveforms only. In this study, surface waves, which dominate the wave field recorded at the surface are removed using a depth filtering technique. The wave field recorded at the surface is datumed to 3.0m depth first. Since surface waves have shallow penetration, they are removed in the datumed wave field which are then re-datumed back to the surface. We then applied waveform tomography to the ground-roll-free wave field from the surface as well as two recording made in two vertical boreholes. We chose 12 frequency components from 12Hz to 200Hz for the tomographic inversion. Using the waveform tomography image of Gao et al.(2001)as the starting model for the waveform inversion, the misfit function was generally reduced by 25.0% 60.0% for different frequency components. The velocity in the final model varies between 120.6m/s and 1649.0m/s, and is highly laterally heterogeneous. Features down to $\sim$1.5m scale size are resolved. Generally we can identify a thin layer at the surface with velocity $\sim$550m/s and a layer with lower velocity, $\sim$150m/s to $\sim$500m/s, beneath it. The low velocity layer extends down to $\sim$8.5m on average. Below the top of the water table at $\sim$9.0m, the velocity increases with depth rapidly, reaching 1500 m/s at $\sim$14m depth. Geologically, the model is interpreted as a thin layer of desert hardpan overlying a heterogeneous layer of dry unconsolidated gravel, grading into increasingly saturated gravels and clay to 16.0m depth.

The waveform tomography velocity model generally agrees with the much coarser model obtained from a 3D travel time tomography (Aron et al., 2002) except for small scale features. Both models have a thin intermediate velocity surface layer underlain by a low velocity layer beneath which velocity increases rapidly. Velocities range from $\sim$150m/s to $\sim$1700.0m/s in both models. The travel time model has less structure than the waveform tomography model, both as a consequence of inverting the waveforms, and the much higher spatial sampling of the shot and receiver wavefields used in the waveform inversion than in the travel time tomography (Δs = 0.70m versus 2.1-2.8m; Δg=35-50cm versus 2.1-2.8m). Comparison of the waveform inversion model with the 3D seismic reflection data (Dana et al., 2002) shows that the rapid change in seismic velocity at the top of the water table corresponds to a moderate strength reflection.

URL: http://terra.rice.edu

S72A-1131 1330h POSTER

3-D, Near-Surface Seismic Reflection Investigation at a Groundwater Contamination Site

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We conducted a near-surface, 3-D seismic reflection survey at a groundwater contamination site. Part of a month-long experiment that included tomography and downhole seismic studies, the experiments were designed to image the near surface (<20m) at a high level of detail (< 0.5m laterally and vertically) to enhance ongoing remediation activities at the site. The site, Operable Unit 2 (OU2), located at Hill Air Force Base in Ogden, Utah has been subject to continuing efforts to remove dense, nonaqueous-phase liquids (DNAPLs) released at the site. Subsurface mapping of the near-surface geology, based on more than 200 monitoring wells drilled at the site, has not been sufficient to allow effective remediation. The near-surface geology of OU2 includes unconsolidated sands, silts and gravels overlying a thick clay aquiclude. Incised in the clay is a paleochannel about 15m deep trapping both groundwater and DNAPL.

The 3-D reflection survey, covering an area of 95 by 37m centered over the channel, used approximately 630 RefTek Texans, a single-channel, non-cabled recording system. Receivers were spaced at 0.35m intervals across the channel profile (east west) with a 2.1m separation along the channel strike (north south). The source, a .223 caliber rifle, was fired in a rotated brick shooting pattern between the receiver lines producing a data set of over 1.8B traces with .175 x .175m CMP bin size. Over 3,700 useable shot records were taken, forming a data volume of 3.6 Gbytes.

After data preprocessing, filtering (90-440Hz passband), velocity analysis and stacking, the 3-D stack shows coherent shallow reflections from the stratigraphy within the channel and the top of the clay layer from 20 to 80ms. Inline sections show the changing channel profile, steeply dipping along the western wall, with a more gentle slope along the east wall. Consistent with depth-to-clay values from the well data, the depth to the base of the channel, the likely collection points for DNAPLS, varies from 60ms to 80ms at different points within the stack. The sections also correlate with our results from the initial 2-D survey at OU2.

Time slices show the lateral extent of the channel. The east edge of the channel is visible at 40ms, and both channel banks are visible at 50ms within the stack. From 70-90ms only deeper portions of the channel are visible within the south portion of the survey. These variations match monitoring well locations at which deeper channel depths were measured. Comparison of the seismic data with maps made from well data show excellent correlation between the separate data sets with the seismic data successfully imaging the varying depth-to-clay at the site from 3 to 15m. The reflection images also agree well with the travel time tomography images of the channel made from the complementary tomography experiment described by Azaria et al (also in this session).

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S72A-1132 1330h POSTER

3-D Seismic Tomography Survey at a Groundwater Contamination Site

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As part of an ongoing environmental characterization project at Hill Air Force Base near Ogden, Utah, a 3-D seismic survey led by a team from Rice University was performed over a contaminated aquifer in 2000. This site contains significant amounts of dense non-aqueous phase liquids (DNAPLs) in a shallow aquifer less than 15 m deep. The aquifer is bounded below by a clay aquiclude, in which a paleochannel acts as

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a trap for the contaminants. The overburden consists of Quaternary sands, gravels and clays. Imaging the structure of the paleochannel at depths up to 15 m is the main target of the survey. The four week experiment included 3-D reflection, 3-D refraction, checkshot surveys and vertical seismic profiles using wells up to 15m deep.

Here we present traveltime tomography results from the 3-D refraction survey which consisted of 596 RefTek Texan recorders deployed uniformly in a stationary rectangular grid over an area of 95m by 36m. A shot from a .223 caliber rifle was fired 30cm from each receiver station, yielding a dataset with about 360,000 traces. The arrival times of the refracted waves were used in a 3-D tomographic inversion to image the seismic velocity structure of the study area. The iterative, nonlinear tomographic approach employs regularization to smooth the model perturbations with respect to a simple 1-D starting/reference model.

The resulting velocity model shows that the near-surface velocity increases by roughly a factor of 5 in the upper 15m, from about 300m/s to 1500m/s. Cross-sections through the model show a north-south trending low-velocity feature interpreted to be the channel structure. The low-velocity feature is best viewed via depth slices which define an anomaly that roughly outlines the geometry of the buried paleo-channel based on well data. A comparison between the 3-D velocity model and time slices through a brute stack of the 3-D reflection data also show close agreement (see Dana et al. this session). Checkerboard tests applied to the velocity model establishes a 7.5m lateral resolution throughout most of the depth range of interest. While the long wavelength features of the model reveal the paleo-channel, the velocity model is likely a broad and smooth characterization of the true velocity structure.

S72A-1133 1330h POSTER

Fracture Detection Using 3D Seismic Data: A Case study

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Oil production from fractured, self-sourced lacustrine shale occurs in many areas of Jiyang Depression, Eastern China. Many information indicated Hydrocarbons within shale is controlled by a fracture system with possible significant lateral connectivity. Characterizing the fractures in this field is of great importance, So the seismic data from the Luo42 3D, acquired over a full 360 degrees azimuthal range, is used to determine the orientation and density of fractures.

The basic theory is that P-wave attributes (traveltime, stacking velocity and amplitude) show elliptical variations along the azimuthal direction in an anisotropic medium induced by vertical fractures. The orientation of the long ellipse indicates the fracture strike and the ratio of the long to short axes indicates the fracture intensity.

Two methods are used to extract the fracture information: surface fitting and narrow-azimuth stacking. The first method fits an elliptical surface to all-azimuths and all-offsets by least-square fitting. The second method divides the data into six narrow-azimuth volumes, with 30 degrees (-150 150) azimuthal bins. Corresponding to these two methods, there are five possible attributes which may be used to extract the fracture information. Surface-fitting has at least three attributes since a surface can be fitted to either bottom-travel time, or interval travel time and/or amplitudes. Two attributes (stacking velocity and AVO gradient) are commonly used for analyzing the narrow-azimuth stacked data.

A full test of all five attributes over Target are performed to identify the most reliable and robust attributes, the results show that surface fitting of interval times and narrow-azimuth stacking velocity are two most robust attributes. These two attributes are not only very robust, but also allow easy compensation of the overburden effects and dip-layer effects, and the amplitudes are generally scattered and less reliable.

S72A-1134 1330h POSTER

Near-Surface Seismic Profiling Across the Active Carlsberg Fault, Denmark

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An integrated near-surface normal-incidence and wide-angle seismic experiment has been conducted across the active Carlsberg Fault in the easternmost part of the Danish basin, just east of Copenhagen. The purpose of the seismic experiment is to: 1) determine the fault structure; 2) image possible seismic velocity contrasts across the fault; and 3) estimate how much the fault offsets the individual sedimentary layers at the different depth levels.

The origin of the Carlsberg Fault is probably related to extensional stresses in a strike-slip system caused by movements in the Sorgenfrei-Tornquist Zone, which is a 20-50 km wide fault zone located approximately 50 km east of Copenhagen. In the study area, the upper sedimentary strata consist of Cretaceous and Danian chalk layers as well as younger sediments, which predominantly consist of sand and clay. The fault runs in an overall NNW-SSE direction, and it penetrates the various sedimentary strata. Geodetic measurements show that the fault has been active within the last 100 years.

The normal-incidence data were collected along an 1100 m long line perpendicular to the strike of the fault with a shot spacing of 12 m and a receiver spacing of 6 m. The reflection image reveals a clear flower structure in the upper 400 ms of the section indicating that substantial horizontal movement has taken place along the Carlsberg Fault. This flower structure is relatively narrow at 350 ms depth, whereas it unfolds to a width of about 300 m in the uppermost layers. The wide-angle data were collected along a 2000 m long line with shot and receiver spacings of 100 m and 10 m, respectively. They provide good velocity control of the sedimentary layers and allow for depth conversion of the reflection seismic image. Furthermore the wide-angle data have the potential of providing back-scattered reflections from the fault planes. GPR measurements have been planned in order to constrain the very shallow and recent movements along the fault.

S72A-1135 1330h POSTER

Seismic Reflection Survey of the Ohchigata Fault Zone Around Hakui City in Ishikawa Prefecture, Central Japan

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The Ohchigata fault zone consists of several faults those extend for 10-20km along the north and south margins of the Ohchi plains. We carried out the seismic reflection survey along two lines, the A and B lines, to determine the precise geological structure of this fault zone. The A line is 5.3km long and cuts across the Ohchigata fault zone. The B line is 1.5km long and cuts across the Sekidosan fault which extends along the south margin of the Ohchi plains and constitutes the Ohchigata fault zone. The vibroseis, the mini vibrator, and the impactor were used as the seismic source along the A line, and the mini vibrator was used along the B line. The intervals of the shot point and the receiving point are 10m and 10m respectively on the A line except around the crest of the north hills. Those are 5m and 5m respectively on the B line. The result shows the gentle southeast inclined structure in the sedimentary layers under the Ohchi plains with the thrust structure on the foot of the north hills and the thrust-like structure on the south margin of the Ohchi plains. Moreover, the seismic reflection profile shows the basement of the possible granite attaining about 1000m asl., and angular unconformity in the upper part of the sedimentary layers under the Ohchi plains. In the B line, the boundary where the P-wave velocity is reversed extends to the foot of the south hills, and seems to coincide the Sekidosan fault.

S72A-1136 1330h POSTER

Additional geological insight brought by 3-D seismic data

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3-D seismic data allows geo-scientists to study the earth at a level that is much more detailed than ever. It is shown in this case study that 3-D seismic can not only be used to identify different types of oil/gas reservoirs, significantly reduce the risk of misinterpretation, but also help to understand geological history and establish paleogeography at different geological times.

In the study of Southeast Maricopa Seismic Survey in southern San Joaquin Valley, two types of potential hydrocarbon traps are interpreted: stratigraphical traps due to turbidite channels, and structural traps due to faulting. The distinctive characteristics of two types of channels indicate different depositional environments. With 3-D visualization tools, it is found that localized faults had been leaking during certain geological times, resulting in structural traps of oil/gas.

A geological history of the local area can be estimated by building a series of pseudo-paleogeographic maps using 3-D seismic data, which further reconfirms the existence of different depositional systems indicated by two distinctive types of channels.

S72A-1137 1330h POSTER

Seismic Borehole Monitoring of CO_2 Injection in an Oil Reservoir

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A series of time-lapse seismic cross well and single well experiments were conducted in a diatomite reservoir to monitor the injection of CO_2 into a hydrofracture zone, based on P- and S-wave data. A high-frequency piezo-electric P-wave source and an orbital-vibrator S-wave source were used to generate waves that were recorded by hydrophones as well as three-component geophones. The injection well was located about 12 m from the source well.

During the pre-injection phase water was injected into the hydrofrac-zone. The set of seismic experiments was repeated after a time interval of 7 months during which CO_2 was injected into the hydrofractured zone. The questions to be answered ranged from the detectability of the geologic structure in the diatomic reservoir to the detectability of CO_2 within the hydrofracture. Furthermore it was intended to determine which experiment (cross well or single well) is best suited to resolve these features.

During the pre-injection experiment, the P-wave velocities exhibited relatively low values between 1700-1900 m/s, which decreased to 1600-1800 m/s during the post-injection phase (-5%). The analysis of the pre-injection S-wave data revealed slow S-wave velocities between 600-800 m/s, while the post-injection data revealed velocities between 500-700 m/s (-6%). These velocity estimates produced high Poisson ratios between 0.36 and 0.46 for this highly porous ($\sim$ 50%) material. Differencing post- and pre-injection data revealed an increase in Poisson ratio of up to 5%. Both, velocity and Poisson estimates indicate the dissolution of CO_2 in the liquid phase of the reservoir accompanied by a pore-pressure increase.

The single well data supported the findings of the cross well experiments. P- and S-wave velocities as well as Poisson ratios were comparable to the estimates of the cross well data.

S72A-1138 1330h POSTER

Determination of Shallow Shear Wave Velocity Profiles Using Ambient Vibrations at Selected Sites in Greece

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The use of ambient vibrations for the determination of subsurface shear wave velocity profiles is increasingly gaining popularity as a low cost alternative to elaborate geotechnical site investigations. Based on

the analysis of synthetic data, it has recently been suggested that robust constraints on both the shear velocity profile and the depth to the first impedance jump can be obtained if single station H/V spectral ratios are jointly inverted together with dispersion curves obtained from array analysis. In order to test this hypothesis, in August of 2002 we have performed array measurements of ambient vibrations at the Euro-SEISTEST in northern Greece, at six different locations within the city of Thessaloniki, and on the island of Lefkas where strong non-linear effect have been observed in a previous study. At all these locations, the subsurface structures are well known and shear wave velocity profiles have been determined by independent geophysical and geotechnical surveys. Furthermore, information about the intensity and damage distribution is available for the city of Thessaloniki. This detailed knowledge, as well as numerous data from temporary and permanent seismological networks makes these locations unique test cases for site response analysis. We present first encouraging results of the comparison of site models obtained from ambient vibrations with the existing structural models and discuss the consequences for site response prediction using ambient vibration recordings.

S72A-1139 1330h POSTER

Comparison of P-Wave and S-Wave Reflection Surveying Effectiveness for Detection of Mine-Related Subsidence Activity Beneath a Heavily Traveled Roadway

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We acquired high-resolution multicomponent seismic reflection data along an undermined 2200 ft (671 m) section of Interstate highway 70 (I-70) in eastern Ohio, in order to identify areas of active subsidence or soil piping into subsurface collapse features. This paper presents results from research conducted: 1) to investigate potential advantages and disadvantages associated with near-surface P- and S-wave reflection surveys, and 2) to determine the subsidence detection potential of common-mode P- and S-wave data components acquired in the study area. P-wave data have traditionally been acquired during shallow reflection surveys, however, the number of reports concerning shallow S-wave surveys is relatively small, and very few reports concerning the concurrent acquisition and analysis of P- and S-wave reflection data exist.

Although S-wave reflections from the top-of-bedrock (located above the coal mine and targeted for subsidence detection purposes) were consistently observed in both XX component (inline-inline, SV-SV) and YY component (crossline-crossline, SH-SH) data, surface wave noise resulted in the optimum reflection window of XX data being relatively narrow. Stacks produced using YY data had a higher signal-to-noise ratio and better imaged the target horizon than those produced using XX data. Whereas S-waves were relatively insensitive to changes in overburden moisture content, P-wave reflections from the top-of-saturated-overburden (located above bedrock) were recorded in ZZ component (vertical-vertical, P-P) data. The arrival times of P-wave reflections and the characteristics of the recorded noise modes made it difficult to process and use P-wave reflections from this interface. P-wave events from deeper impedance contrasts were not observed in field data due to several factors: surface wave and air wave noise, a high P-wave reflection coefficient at the top-of-saturated-overburden, low P-wave reflection coefficients at deeper interfaces, and interference effects/resolution issues. Calculations suggest that the resolution of S-waves in the study area dry overburden is more than 1.7 times that of P-waves, and that the resolution of S-waves in the study area saturated overburden is more than 4.5 times that of P-waves.

Given the study area subsurface conditions and acquired data characteristics, areas of the subsurface where subsidence processes have been active could be most accurately delineated through the processing and interpretation of YY (relative to XX and ZZ) data. Processed YY data indicate that the bedrock horizon is significantly disrupted due to mine-related subsidence processes at numerous locations along the roadway in the study area. Hence, these locations are regarded as having a relatively high risk for future mine-related surface failure.

S72A-1140 1330h POSTER

3-D Waveguide Effects of Topographical Structural Variation on Full Waveform Propagation: 3-D Finite Difference Modeling Comparisons with Field Data From Yuma Proving Ground, Arizona

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The propagation of seismic waves through regions of complex topography is not thoroughly understood. Surface waves, are of particular interest, as they are large in amplitude and can characterize the source depth, magnitude, and frequency content. The amplitude and frequency content of seismic waves that propagate in regions with large topographical variations are affected by both the scattering and blockage of the wave energy. The ability to predict the 3-d scattering due to topography will improve the understanding of both regional scale surface wave magnitudes, and refine surface wave discriminants as well as at the local scale (<2 km) where it will aid in the development of rule of thumb guide lines for array sensor placement for real time sensing technologies. Ideally, when validating the numerical accuracy of a propagation model against field data, the input geologic parameters would be known and thus eliminates geology as a source of error in the calculation. In March of 2001, Kansas Geological Survey (KGS) performed a detailed seismic site characterization at the Smart Weapons Test Range, Yuma Proving Ground, Arizona. The result of the KGS characterization study is a high-resolution 3-d model that is used in our seismic simulations. The velocities Vs, Vp are calculated by tomography and refraction, attenuation coefficients estimated from the surface wave and from p-waves and are provided in a model with attributes resolved in 3-d to 0.5 meters.

In the present work, we present comparisons of synthetic data with seismic data collected at the Smart Weapons Test Range to benchmark the accuracy achieved in simulating 3-d wave propagation in the vicinity of a topographical anomaly (trench). Synthetic seismograms are generated using a 3-d 8th order staggered grid visco-elastic finite difference code that accounts for topography. The geologic model is based on the Yuma site characterization. The size of these calculations required use of the DoD High Performance Computers and parallelized code. Results are compared with field data. Preliminary results show an excellent match with field data using the 3-d fdtd technique.

S72B MCC: Hall C Sunday 1330h

Radiated Energy and Apparent Stress: Constant or Nonconstant Scaling? II Posters *(joint with T)*

Presiding: **L Zhu,** Saint Louis University**; I M Tibuleac,** Weston Geophysical Corporation

S72B-1141 1330h POSTER

Scaling of Earthquake Source Parameters for Small Earthquakes Recorded at the Western Nagano, Japan Deep Borehole

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The scaling of stress drop and apparent stress with seismic moment for small earthquakes (M<3) has been the subject of much discussion and research but the question remains unresolved. In this work 90 earthquakes of -0.5<M<3.0 were studied using recordings made at the 800m deep borehole in western Nagano, central Japan. Data is recorded at a sampling rate of 10kHz and spectra show high signal to noise ratio up to frequencies of 200-300Hz. High quality recordings of nearby earthquakes make it possible to determine good estimates of seismic moment and energy for small events.

The P and S wave direct arrivals were picked on velocity seismograms and amplitude spectra for the events were fitted with an ω^2 model comparing results obtained for different length P and S wave time windows. Source parameters were calculated using frequency dependent and independent quality factors (Q values). Q(f) values were calculated using the extended coda normalisation method of Yoshimoto et al. (1993) and the results compared to the relationships obtained by previous studies in this area (Yoshimoto et al.,1998 and Matsuzawa et al., submitted for publication). The Q(f) values obtained increased with frequency and were found to agree with the results of the previous studies. A breakdown in scaling of apparent stress with moment was observed for seismic moments around 10^{11}Nm with results for frequency dependent and independent Q. This indicates the assumption of a constant Q is valid in this case. No change in scaling of static stress drop with moment was observed above 10^{10}Nm but an investigation into the restrictions the instrumentation places on the analysis revealed that the results for events with Mo<10^{10}Nm are unreliable.

The possibility of the change in apparent stress scaling being dependent on area and/or hypocentral distance was investigated. No area dependence was observed but a decrease in apparent stress was found with increasing hypocentral distance and the effect becomes obvious at shorter distances for smaller events. A similar but less striking trend was seen for stress drop values. This result leads to the conclusion that path effects are the cause of the observed trend in apparent stress scaling and therefore they must be considered for small events even in the analysis of clean seismograms recorded by deep boreholes.

S72B-1142 1330h POSTER

Source scaling relationships of small earthquakes estimated from the inversion method using stopping phases

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We estimate source parameters of small earthquakes from stopping phases and investigate the scaling relationships between source parameters. The method we employed [Imanishi and Takeo, 2002] assumes an elliptical fault model proposed by Savage [1966]. In this model, two high-frequency stopping phases, Hilbert transformations of each other, are radiated and the difference in arrival times between the two stopping phases is dependent on the average value of rupture velocity, the source dimension, the aspect ratio of elliptical fault, the direction of rupture propagation and the orientation of the fault plane. These parameters can be estimated by a nonlinear least squares inversion method. Earthquakes studied occurred between May and August 1999 at the western Nagano prefecture, Japan, which is characterized by high levels of shallow earthquakes. The data consist of seismograms recorded by an 800 m deep borehole and a 46 surface seismic array whose spacing is a few km. In particular, the 800 m borehole data provide a wide frequency bandwidth and greatly reduce ground noise and coda wave amplitude compared to surface recordings. High-frequency stopping phases are readily detected on accelerograms recorded in the borehole. After correcting both borehole and surface data for attenuation, we also measure the rise time, which is defined as the time lag from the arrival time of the direct wave to the first slope change in the displacement pulse. Using these durations, we estimate source parameters of 25 earthquakes ranging in size from M1.2 to M2.6. The rupture